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# Update of Innovative Thermal Destruction Technologies

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16. ABSTRACT

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# UPDATE OF INNOVATIVE THERMAL DESTRUCTION TECHNOLOGIES

by

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# UPDATE OF INNOVATIVE THERMAL DESTRUCTION TECHNOLOGIES

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## I. ABSTRACT

Five innovative technologies for thermally destroying hazardous wastes were selected and described in this paper. They are Oxygen-Enriched Incineration, Westinghouse/O'Connor Combustor, Circulating Bed Combustion, Infrared System, and Plasma Arc. Two important criteria used in selecting these technologies are that they are at least at the stage of pilot-scale demonstration and appear to be promising in terms of destruction effectiveness.

## II. INTRODUCTION

The disposal of solid wastes is an environmental issue of the 1980s and will continue as long as waste is continuously produced. EPA's research data and industry's operating experience indicate that incineration, when compared to the other alternative technologies, has the highest overall degree of destruction and control for the broadest range of various waste streams (Ref. 1). The waste streams may include hazardous waste, municipal waste, toxic substances (PCB), hospital waste, spent pesticides, sludges from both municipal and industrial wastewater treatment processes, and other unclassified waste such as military waste.

Incineration has been used for waste disposal for many decades. Major conventional incineration technologies used for various waste types are summarized in Table 1.

Table 1. Waste Types and Their Conventional Incineration Technologies

| Waste Type | Conventional Incineration Technologies |
|---|---|
| 1. Hazardous Waste | * Rotary kilns<br>* Liquid injection incinerators |
| 2. Medical Waste | * Excess-air modular incinerators<br>* Starved-air (two-stage) modular incinerators |
| 3. Municipal Waste | * Mass-burning incinerators<br>* Refuse-derived fuel (RDF)-burning incinerators |
| 4. Industrial sludges | * Multiple hearths<br>* Fluidized beds |
| 5. Municipal sludges | * Multiple hearths<br>* Fluidized Beds |

One of EPA's functions in their RCRA and Superfund programs is to assist industry in developing innovative technologies for waste destruction. Their main activities in this area are described below.

During 1980-1984, EPA's Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio sponsored a research program under RCRA to evaluate the performance of innovative thermal technologies for hazardous waste destruction. The program selected and tested the following six innovative technologies. The testing results were summarized in C. C. Lee's 1983 paper entitled "A Comparison of Innovative Technology for Thermal Destruction of Hazardous Waste" (Ref. 2) for:

* Fluidized bed
* Molten salt
* Advanced electrical reactor
* Plasma arc
* Wet air oxidation
* Supercritical water

As a result of the 1980 Superfund Act, industry began to develop transportable incineration systems aimed at destroying both industrial and dump-site remedial waste. In 1986, the Superfund Amendments and Re-authorization Act (SARA) required EPA to establish a Superfund Innovative Technology Evaluation (SITE) program to specifically support innovative technology demonstrations each year. So far, EPA has selected 21 technologies for funding support under the SITE program. Of the 21 technologies, five technologies are thermal processes as shown in Table 2.

Table 2. SITE-Supported Innovative Thermal Technologies

| Technologies | Testing Status |
|---|---|
| * Infrared system | Testing results are included in this paper. |
| * Circulating bed combustor | Testing results are included in this paper. |
| * Westinghouse plasma arc | No testing data available yet. |
| * Westinghouse electric pyrolyzer | No testing data available yet. |
| * Centrifugal reactor | No testing data available yet. |

This paper is to update C. C. Lee's 1983 paper. It describes selected innovative technologies supported either by EPA's RCRA and SARA programs or developed by industry since 1980. Two of the

important criteria used in selecting these technologies are that they are (or had been) at least at the stage of pilot-scale demonstration and appear to be promising in terms of destruction effectiveness. The technologies selected for this paper are listed in Table 3.

Table 3. Innovative Technologies

| Process | Key Feature |
|---|---|
| 1. Oxygen-Enriched Incineration | High-temperature oxidation (1500-2000 F). High-purity O2 is used as a replacement for combustion air(so, gas flows and N2-content are low). |
| 2. Westinghouse/ O'Connor Combustor | High-temperature oxidation (1500-2000 F). It reportedly can be used for both hazardous waste and municipal waste incineration. |
| 3. Circulating-Bed Combustor (CBC) | Low-temperature oxidation (1000-1500 F). Incineration coupled with simultaneous removal of products by bed materials which are generally lime or limestone powders. |
| 4. Infrared System | High-temperature pyrolysis or oxidation (1500-2000 F). It can be operated under starved- air or excess air conditions. |
| 5. Plasma Arc | High-temperature pyrolysis (18,000 F). Plasma is an ionized gas flow which breaks the bond of chemical compounds in a micro-second. |

## III. TECHNOLOGY DESCRIPTIONS

### A. Oxygen-Enriched Incineration

#### 1. Process Description

Successful hazardous waste incineration requires an intensive, complete destruction/oxidation of waste molecules with oxygen. Current incinerators require about 150% excess air to provide enough oxygen for oxidation, and require that the so-called 3-T factors (temperature, turbulence, and residence time) be adequate to insure efficient destruction. Because 79% of air is nitrogen, the majority of any excess air used will not contribute to the effectiveness of incineration and will only result in extra energy required to raise the nitrogen to combustion temperature, and additional product gas handling and cleaning requirements. As a matter of fact, two of the 3-T's (turbulence and residence time) are essentially the physical parameters used to promote the contact of hazardous waste particles with oxygen. Therefore, it is seems logical that increased oxygen concentration should improve

incineration or destruction efficiency.

In 1987, under the sponsorship of EPA's Office of Research and Development, the Union Carbide Corporation (UCC) tested its oxygen-enrichment burner, the Linde Oxygen Combustion System (OCS), on EPA's Mobile Incineration System (MIS). The burn took place using the dioxin-contaminated solids and liquid waste located at the Denney Farm in McDowell, Missouri. EPA's MIS was built in 1981 (Ref. 3). It originally consisted of four heavy duty, over-the-road semi-trailers. They were:

* Trailer 1: Rotary kiln (4.9 MMBtu/hr, i.e., million Btu/hr)
* Trailer 2: Secondary combustion chamber (3.9 MMBtu/hr)
* Trailer 3: Scrubber and air pollution controls (APC)
* Trailer 4: Combustion and stack gas monitoring equipment

The conventional air burner system was replaced by the Linde OCS. The Linde OCS consists of the patented "A" Burner , an oxygen flow control piping skid and a control console (Refs. 4,5,6). The control console utilizes a programmable controller to optimally integrate all system components into a flexible combustion package while providing for easy operator interfacing and safety interlocking. The "A" Burner allows the use of up to 100% oxygen in place of air for incineration without creating high flame temperatures, high NOx, poor mixing and non-uniform heat distribution. However, for incinerators under even a slight vacuum, close to 100% oxygen enrichment would be very difficult to achieve due to the inevitable air infiltration.

2. Case Study Results

Operation of the modified MIS from early June to mid-September 1987, reportedly confirmed that the system had achieved the following major research goals (Ref. 4).

* Throughput increase
* Specific fuel savings over 60%
* Kiln puff reduction

Each of these achievements is described below.

a. Throughput Increase

The maximum contaminated soil throughput of the Mobile Incineration System during its operation with air burners was designed to be 2000 lb/hr. However, this maximum rate was not sustainable. For example, the average throughput rate of four test runs in the Spring of 1985 had been only 1478 lb/hr. With the Linde Oxygen Combustion System, the MIS achieved a sustainable soil throughput rate of 4000 lb/hr, as confirmed by a certified verification test. The comparison of the two sustainable conditions is shown in Table 4.

Table 4. EPA Mobile Incineration System: Oxygen Demonstration Result Summary

| | AIR CASE+ | OXYGEN CASE | PERCENT CHANGE |
|---|---|---|---|
| Contaminated Soil (lb/hr) | 1478 | 4000 | +171% |
| Firing Rate (MMBtu/hr) | | | |
| Kiln | 4.9 | 3.9 | |
| SCC (Secondary Combustion Chamber) | 3.9 | 5.4 | |
| Total | 8.8 | 9.3 | +6% |
| Specific Fuel Use (MMBtu/Ton Soil) | 11.9 | 4.7 | -61% |
| Pure Oxygen Input (lb/hr) | | | |
| Kiln* | | 574 | |
| SCC | | 0 | |
| Total | | 574 | |
| Specific Oxygen Consumption (Ton O2/Ton Soil) | | 0.14 | |
| Fuel Savings (MMBtu/Ton O2) | | 50 | |
| Kiln Superficial Velocity** (Ft/Sec) | 8.1 | 3.3 | -59% |
| SCC Residence Time** (sec) | 2.6 | 2.6 | 0 |
| Quenched Gas Flow (DSCFM) | 3250 | 2500 | -23% |

Note: + Average of four runs. Maximum throughput was 2000 lb/hr
* 58% of total oxygen entering the kiln (Equivalent to 40% O2 Enrichment)
** Calculated data

b. Fuel Savings

Without oxygen enrichment, supplemental fuel was added to provide the heat required to operate the rotary kiln at 1500-1600 F and the secondary combustion chamber at about 2100 F, because the waste materials did not have a sufficient heating value to sustain self-combustion.

Specific fuel savings of over 60% was achieved during operation of the EPA/MIS with the Linde system. This result can also be expressed as 50 MMBtu saved per ton of oxygen used, as shown in Table 4.

The economics of using oxygen to save fuel, of course, depend on the relative cost of fuel and oxygen. With No. 2 fuel oil costing $0.70 per gallon (or $5.50 per million Btu) and a fuel savings of about 50 million Btu for every ton of oxygen used, the breakeven oxygen cost is $275 per ton of oxygen. The cost of oxygen depends on the method of oxygen generation, the size of the plant, and the location. For example, it ranges from about $50 per ton of oxygen produced by a large on-site facility to about $120 per ton for delivered liquid.

c. Kiln Puff Reduction

When high-Btu wastes are fed into rotary kiln incinerators in an intermittent mode, the transient combustion behavior of these materials create unsteady releases of combustible gases which may momentarily deplete the oxygen supply to the incinerator. These temporary oxygen deficient conditions could cause the release of products of incomplete combustion (PICs) and often are called kiln "puffs" (Refs. 7,8).

In the field operation of the EPA/MIS, large quantities of plastic materials were burned periodically. These materials were ramfed in the rotary kiln every 1-2 minutes. To respond to the transient oxygen demand for burning these materials, an oxygen feed-forward/ feedback control logic was designed into the Linde system. Automatic water spray was used to modulate kiln temperature when required.

Before the implementation of this O2 control feature, the MIS had difficulty in burning these plastic materials smoothly, partly due to its relatively small capacity. Shown in Figure 1 are examples obtained during the early shakedown period. Even though the normal excess oxygen level was high, occasional feeding-practice upsets caused puffs to occur as evidenced by the drop in the O2 concentration (to close to 0%) and the CO spikes.

After the implementation of the oxygen control feature, the transient upset conditions associated with the release of the combustible gases were virtually eliminated in the operation of the MIS. As shown in Figure 2, the oxygen level of the gas entering the SCC was controlled to be within + 1% from the setpoint of 9% O2, while the O2 level at the SCC is maintained at about 6% (dry). Carbon monoxide spikes were not detected. Note also in Figure 2, the oxygen flow rate responded promptly to the transient oxygen demand.

3. Current Technology Status

Although Union Carbide Company (UCC) completed its burn evaluation with the MIS, EPA is continuing to use UCC's burner to test-burn other wastes. Test results relative to destruction and removal efficiency (DRE) may be available later.

In addition to UCC's oxygen-enrichment tests, the American Combustion Company (ACC) also tested its Pyretron oxygen-enrichment burner at EPA's Combustion Research Facility (CRF) in Jefferson, Arkansas. Testing results are being evaluated at this writing.

4. Technology Advantages (Ref. 4)

a. When using oxygen-enrichment, the waste throughput of the incinerator, which is normally limited by the air blower capacity, and the gas residence time can be significantly increased.

b. The fuel consumption, if supplemental fuel is required, is lowered primarily due to the reduced sensible heat loss to the flue.

c. The DRE should be improved due to the higher oxygen concentration in the fuel-oxidant mixture and the longer residence time.

d. Pollution control of the reduced flue gas is less costly and more effective.

5. Technology Disadvantages

a. Because of less diluents such as N2 in the combustion off-gas system, oxygen-enriched incineration, in general, has higher flame temperatures compared to the conventional air-only incineration. The higher flame temperatures often results in higher NOx formation and local overheating.

b. Oxygen supply (and cost) is the major problem associated with oxygen-enriched incineration.

B. Westinghouse/O'Connor Combustor

1. Process Description (Ref. 9)

The heart of the system is the Westinghouse/O'Connor combustor, a water-cooled rotary barrel constructed of alternating longitudinal water tubes and flat perforated steel plates welded together to form the perimeter. The combustor is installed on a slight incline and is slowly rotated by a chain and roller drive. The perforations between the water tubes provide controlled distribution of combustion air, while the water cooled walls remove heat and protect the barrel from overheating.

Waste is fed directly from the receiving area into the upper end of the tilted combustor. As the waste tumbles down the length of the rotating barrel, it dries and then progressively burns. Ash dropping out of the lower end is about one tenth of the original waste volume; remaining unburned material is more completely combusted in an afterburner grate.

The City of Panama City, Florida constructed two Westinghouse/O'Connor units at its Bay County Resource Management Facility to incinerate 510 tons per day of municipal solid waste (MSW) in 1987 (Ref. 9). Heat generated by the combustion of waste produces steam to drive a turbine generator. A process flow diagram of the Bay County facility is shown in Figure 3. The plant consists of two combustor/boiler units, a turbine-generator, a truck scale, tipping floor, front-end loaders, conveyers, air pollution control equipment, a stack, ash handling equipment, a central control room, and all required ancillary equipment. The facility also includes administration offices, change rooms, parking areas, roadways, and security fencing.

All MSW received at the plant enters through an automatic gate system and is unloaded on the tipping floor. Large items are separated from the MSW; the large combustible items are processed through a shear shredder; the large noncombustible items are removed and stored temporarily for landfill disposal. After sorting, the MSW is then fed into the combustor to begin its incineration. The slightly-inclined combustor barrel rotates slowly, causing the waste to tumble and advance as combustion proceeds. A forced-draft fan draws combustion make-up air from the tipping area to reduce odor and dust levels in the tipping hall and to prevent them from escaping the building. The air is preheated before entering the multiple zone windbox located beneath each combustor barrel.

Figure 4 shows the cross-section of the rotary combustor and the flow of underfire and overfire air into the combustor. The combustor barrel has a diameter of 10 feet and is constructed by alternating steel tubes with carbon steel perforated webs and welding them together. The steel webs have a width of 1-1/2 inches with 3/4-inch diameter holes used to bring in combustion air. The tubes direct cooling water through the outside wall of the combustor barrel which upon heating is delivered to the boiler through the rotary joint. Hot gases, produced during the combustion process, flow from the combustor barrel through the boiler's radiant, superheater, and convection sections. The combustion gases exiting the convection section pass through a heat exchanger that preheats the incoming combustion air.

The flue gases from the air heater enter the electrostatic precipitator (ESP) to remove particulate matter before exiting the stack. The flue gas is drawn from the ESP by an induced-draft fan before being discharged to the atmosphere through a separate flue in the common stack.

Three types of ash by-products are produced by the process: fly ash, siftings, and bottom ash. Fly ash is collected in hoppers under the convection, superheater, air heater, and ESP sections of each combustor/ boiler train and is conveyed pneumatically to the bottom ash conveyer. Siftings are collected underneath the combustor by the siftings conveyer and are transferred by an ash drag system to the bottom ash conveyer. Bottom ash falls from the rotary combustor onto a fixed afterburner grate located beneath the combustor outlet. The fly ash, siftings, and bottom ash mixture are water-quenched, dewatered, and removed by one of two redundant bottom ash drag conveyers into trucks, then disposed of in a landfill.

### 2. Case Study Results

Particulate emission was tested on the Panama City units from April 22 through June 5, 1987 (Ref. 9). The results indicate that both Units 1 and 2 are in compliance with the particulate and visual emissions levels required by the State of Florida Department of Environment's PSD Regulations. The PSD (Prevention of Significant Deterioration) Regulations require particulate matter emissions to be less than 0.03 gr/dscf corrected to 12% CO2 and limits plume opacity to no more than 10%. The particulate

matter concentration levels at the design capacity of 255 tons of MSW per day per unit averaged 0.0193 gr/dscf at 12% CO2 for Unit 1 and 0.0243 gr/dscf at 12% CO2 for Unit 2. The EPA Method 5 particulate measurements conducted for determining compliance on June 4 and 5 are given in Table 5. The EPA Method 9 opacity measurements were consistently at or less than 10% for both units during the test runs.

Table 5. Emission Compliance Test Results from the Bay County Resource Management Center

| Date | Time | Flue Gas Flow kdscfm | Flue Gas Flow kacfm | Stack Temp deg F | Steam Flow klb/hr | Percent of Rated Capacity | Particulate Matter gr/dscf @ 12% CO2 |
|---|---|---|---|---|---|---|---|
| Bay County Compliance Test Results - Unit 1 | | | | | | | |
| 6/5 | 959 | 25.8 | 52.4 | 425.0 | 71.1 | 104.5 | 0.0140 |
| 6/5 | 1140 | 27.9 | 55.1 | 429.0 | 66.5 | 97.8 | 0.0240 |
| 6/5 | 1307 | 25.8 | 52.8 | 427.0 | 65.0 | 95.6 | 0.0200 |
| Average | | | | | 67.5 | 99.3 | 0.0193 |
| Bay County Compliance Test Results - Unit 2 | | | | | | | |
| 6/4 | 945 | 27.7 | 52.6 | 429.0 | 69.7 | 102.5 | 0.0250 |
| 6/4 | 1310 | 28.4 | 58.1 | 449.0 | 62.7 | 92.2 | 0.0190 |
| 6/4 | 1525 | 29.2 | 59.0 | 451.0 | 62.3 | 91.6 | 0.0290 |
| Average | | | | | 64.9 | 95.4 | 0.0243 |

Gaseous emissions tests were also conducted during April through June, 1987 to determine the stack gas concentration of SO2, NOx, and HCl. The testing was conducted to verify the emission factors used to project the annual emission rates in the PSD permit application. EPA Method 8 was used to determine SO2 emissions. The average SO2 concentration from 9 tests performed on 5 days was 111 ppmdv corrected to 12% CO2 [dv = dry volume]. A CEM (Continuous Emissions Monitor) was used to measure NOx emissions over a 9-day test program. EPA Method 7 was also used to verify the NOx levels measured by the CEM during an 8-hour period by simultaneous sampling. The average of the NOx emissions data from the CEM and EPA Method 7 were 180 and 157 ppmdv corrected to 12% CO2, respectively, for the eight-hour test. NOx emissions measured by the CEM during the 9-day test period were in the range of 150 to 200 ppmdv with a maximum of 300 ppmdv during boiler excursions. NIOSH Method 112B was used to determine HCl concentrations. Twenty samples were taken on seven different days with an average HCl concentration of 467 ppmdv corrected to 12% CO2.

3. Current Technology Status

Currently, there are 11 modular combustors in operation at 6 different facilities. Three facilities with a total of 7 combustors are under construction and Westinghouse has contracted to

construct 4 more plants with a total of 14 combustors. This represents an aggregate processing capacity of more than 9000 tons of solid waste per day. It appears that the technology has good potential for the future (Ref. 9).

4. Technology Advantages

a. The technology can reportedly handle a variety of wastes including municipal wastes, hazardous wastes and possibly even hospital wastes. It can burn liquids, semi-solids, solids, sewage sludges, and residual oils or refinery bottoms.

b. The technology can be quite flexible in that the modular design concept can be applied to it. Individual units can be as large as 500 tons-per-day of MSW and therefore 4 units would allow for over 2000 tons-per-day capacity. Units can be added as required.

c. The technology has a high energy recovery efficiency, because the water tubes are used as an integral part of the reactor wall.

5. Technology Disadvantages

a. Siftings from the combustion chambers may contain residuals which are not completely incinerated.

b. The technology has not been fully demonstrated yet on hazardous wastes.

C. Circulating Bed Combustor (CBC)

1. Process Description (Ref. 10)

Conventional technologies for the thermal destruction of wastes are often faced with operation at high temperatures with relatively low throughputs and must use afterburners and scrubbers. Ogden Environmental Services, Inc. (OES) has developed a circulating bed combustor (CBC). The CBC uses lower temperatures, compared to conventional rotary kiln or liquid injection incinerators, to obtain the same destruction efficiency as high temperature processes and relatively higher throughputs at a lower thermal rating, reportedly eliminating the need for afterburners or scrubbers.

The CBC uses high-velocity air to entrain circulating solids in a highly turbulent combustion loop. The configuration of a typical CBC system is shown schematically in Figures 5 and 6. The combustion chamber is typically 30 ft high and has a 12-in. thick ceramic liner. Solid feed is introduced into the combustor loop at the loop seal where it immediately contacts the hot recirculating solids stream exiting the hot cyclone. Liquid feeds are typically injected directly into the combustion zone of the CBC. Upon entering the CBC, hazardous materials are rapidly heated and continue to be exposed to high temperatures (1450 to 1600 F) throughout their stay in the CBC. Residence times in the combustor range from 2 seconds for gases to 30 minutes for larger feed materials (<1.0 in.). The high

combustion-air velocity for circulating solids create a uniform temperature (+/- 50 F) around the combustion loop (combustion chamber, hot cyclone, return leg), reportedly resulting in extremely efficient combustion and eliminating the need for an afterburner. During operation, ash is periodically removed from the CBC by means of a water-cooled ash removal system. The hot gas leaving the cyclone is cooled in a flue gas cooler and particulates escaping the cyclone are collected in fabric filter baghouses.

Table 6 shows the generic chemical reactions which take place in the CBC and enable the conversion of harmful acid gases to salts. The rapid combustion and quick neutralization of acid gases within the combustion chamber effectively eliminates the need for high alloy combustor components or post-burner treatment units, such as wet or dry scrubbers, for acid gas capture.

Cooling removes the thermal energy that is released during combustion reactions. Recovery of energy is accomplished in both the combustor zone and the flue gas cooler. In the combustion chamber, the heat transfer is enhanced due to solid particle contact with the cooling tubes. Sensible heat is further removed from the flue gas with conventional heat exchangers located between the cyclone and baghouse filters. Because acid-gas scrubbing takes place within the combustion chamber, the flue-gas coolers are not subjected to the high acid gas concentrations prevalent with conventional waste combustors.

Table 6. Chemical Reactions That Occur in CBC Combustion Chamber

| Reactants | Intermediates | Final Products |
|---|---|---|
| (CxHy + O2 (Hydrocarbons) | ----------> | CO2 + H2O |
| (CxHy)Sz + O2 (Sulfur Compounds) | --------> SO2 | |
| | SO2 + 1/2 %O2 ------> | CaSO4(s) (Gypsum) |
| CaCO3 (Limestone) | ----------> CaO + _____ | + CO2 |
| | CaO + 2 HCl ----------> | CaCl2(s) + H2O (Salt) |
| (CxHy)Clz (Chlorine Compounds) | ----------> 2 HCl | |

2. Case Study Results

A 2 million Btu/hr pilot plant was built in San Diego, California. Development and testing programs at this facility have demonstrated the flexibility and effectiveness of the CBC in destroying a wide variety of hazardous wastes (Ref. 11). Table 7 lists key data from several waste test burns. The test results indicate that 99.99% DRE is readily attainable for many sludge-like

and chemical wastes.

Table 7. Circulating Bed Test Results on Chemical Feeds (a)

| Waste | Form | DRE(%) | HCl Capture, % | Ca/Cl2 Ratio |
|---|---|---|---|---|
| Carbon Tetrachloride | Liquid | 99.9992 | 99.3 | 2.2 |
| Freon | Liquid | 99.9995 | 99.7 | 2.4 |
| Malathion | Liquid | >99.9999 | ---- | --- |
| Dichlorobenzene | Sludge | 99.999 | 99 | 1.7 |
| Aromatic Nitrile | Tacky solid | >99.9999 | ---- | --- |
| Trichloroethane | Liquid | 99.9999 | 99 | 1.7 |
| PCB | Liquid | >99.9999 | ---- | --- |

Notes: (a) Results were obtained in tests at the Ogden Environmental Inc., pilot plant.

3. Current Technology Status

In 1986, EPA's SITE program also selected OES's CBC for Superfund waste destruction testing. According to OES, its first unit (with a 36-inch diameter reactor), that is especially designed for Superfund waste cleanup, will be deployed to a Superfund site in mid-1988. However, no Superfund site has yet been selected.

4. Technology Advantages

a. Because of its intimate contact with heated bed particles, wastes can be combusted at lower temperatures than that of conventional incinerators.

b. Temperatures in the vessel are reportedly high enough to destroy wastes, but low enough to prevent formation of significant amounts of NOx.

c. The bed material acts as a scrubber to capture acid gas from the process, reportedly creating a non-toxic solid residue.

5. Technology Disadvantages

a. Disposal of the supposedly inert residual bed material may represent a problem (if the removed bed materials are considered to be hazardous, they would have to be disposed of at a secure landfill site).

b. Removal of the residual materials from the bed is a potential problem area. As waste combustion proceeds, non-combustible ash accumulates in the bed. Beds with higher than 20 wt% ash are undesirable since at ash levels of this magnitude,

defluidization can occur.

c. Relatively large amounts of fine particulate matter entrained in the exhaust gases may require elaborate pollution control devices.

d. Waste feed particle size must be controlled to maintain a uniform feed rate.

e. Accurate control is needed to ensure that retention time in the bed is sufficient for complete combustion, and that radical increases in the waste's heat value will not drastically boost bed temperatures and adversely affect bed operation.

f. Sophisticated analytical methodologies for the analysis of hazardous residues in the spent bed materials may be required. The analysis is normally required to determine how much unburned waste remains in the residues and to examine how much waste residue is leachable to the environment. It is quite possible that milligram amounts of hazardous materials may remain in the spent bed materials undetected. Disposal of the spent materials could then recycle the hazardous material back into the environment. This situation would be especially dangerous in the case of chemical warfare agents.

## D. Infrared Systems

### 1. Process Description

In general, an Infrared System has the following major components:

a. Primary Combustion Chamber (PCC). The electric-powered PCC utilizes a high-temperature-alloy wire-mesh belt for waste feed conveyance and is capable of achieving temperatures up to 1850 F by exposure to infrared radiant heat provided by horizontal rows of electric-powered silicon carbide rods located above the conveyer belt.

b. Secondary Combustion Chamber (SCC). The gas-fired SCC is capable of reaching temperatures of 2300 F; it provides residence time, turbulence and supplemental energy, if required, to destroy gaseous volatiles emanating from the waste.

c. Air Pollution Control Equipment (APCE). The equipment includes an emissions control system where particulates are removed generally in a venturi section, acid vapor is neutralized in a packed tower scrubber, and an induced draft blower draws the cleaned gases from the scrubber into a free-standing exhaust stack.

d. Process Management and Monitoring Control Center. The Center contains all process and mechanical controls and monitors, including control panels, emissions monitors, motor control units, and office space.

### 2. Case Study Results (Ref. 12)

Beginning in the 1950's, Peak Oil Company operated a used oil processing facility at a site on Reeves Road in Brandon, Florida. Various liquid and sludge waste streams from the re-refining operation which included toxic organics and heavy metals were dumped into an existing natural lagoon located on the property.

The lagoon has some 7,000 tons (and approximately the same number of cubic yards) of material in it and is about one quarter to one half of an acre in size.

EPA's Region IV office in Atlanta initiated actions for a cleanup program. The Regional Office contracted with the firm of Haztech, Incorporated, an emergency response contractor, to proceed with the clean-up program. EPA's Hazardous Waste Engineering Research Laboratory (HWERL) in Cincinnati, through its Superfund Innovative Technology Evaluation (SITE) program, also participated in the cleanup for this particular lagoon. The HWERL effort primarily involved on-site monitoring and the performance evaluation of the Infrared System.

Initial efforts required that the lagoon be drained of water; the remaining sludge was mixed with sand, soil, and lime to form a waste/soil solid matrix that could be handled by earth-moving equipment. (The lime, in addition to providing binder to the moisture-laden matrix, also counteracted and neutralized the acidic properties of the waste.) This approach greatly facilitated the use of the Infrared System (with a high-temperature afterburner). The SITE demonstration of this innovative incineration system was carried out between July 31, 1987 and August 5, 1987.

The waste/soil matrix was excavated from the lagoon area and screened with a power screen. This device effectively broke up the lumpy waste, blended and aerated the feed, and prepared it for further processing. The screening system allowed the one inch and smaller clumps to be separated from the rock, roots, and other extraneous material found in the lagoon. From the power screen, the waste feed soil was weighed and conveyed to the Infrared System.

The Infrared System was brought to the site in four individual units consisting of: (a) a 67-foot long electrically heated infrared primary chamber capable of gas temperatures up to 1850 F; (b) a 72-foot long gas-fired secondary combustion chamber (afterburner) capable of reaching temperatures of 2300 F; (c) an emissions control system with a 60-foot tall stack; and (d) a process management and monitoring control center.

Wastes were metered, spread to the proper width, leveled to optimum process thickness and were fed into the PCC at a rate of 3.6 to 4.0 tons per hour in this nominal 100 ton-per-day unit. The waste was exposed to infrared radiant heat provided by horizontal rows of electric-powered silicon carbide rods located above the conveyer belt. Typically, the waste was retained on the primary chamber conveyer belt for 18 to 19 minutes. The processed feed material dropped off the end of the belt into a discharge module and was quenched with water sprays prior to being discharged by the screw

conveyer system to an outside receiving container.

Exhaust gases from the primary combustion chamber were introduced into the secondary combustion chamber which provided over 3.0 seconds of residence time, turbulence and supplemental energy to destroy any gaseous organics from the primary furnace. The gases leaving the secondary combustion chamber were quenched, particulates were removed in a venturi section, and acid vapor was neutralized in a packed tower scrubber using a sodium hydroxide solution. An induced-draft fan drew the cleaned gases from the scrubber into the exhaust stack which was equipped with sample ports.

During a series of 3 replicate test runs, samples of the solid waste feed, liquid streams, furnace ash, and stack gas emissions were obtained under rigorous, EPA-approved sampling protocols and quality assurance criteria. The most intricate sampling procedures involved the stack gas emissions collection. Sampling methods included a Method 5 train for HCl and particulates, and a Source Assessment Sampling System (SASS) for PCBs, dioxins, furans and semi-volatile priority pollutants. A modified Method 5 train for soluble chromium, a Volatile Organic Sampling Train (VOST) for volatile priority pollutants, and various continuous emission monitors (for O2, CO2, CO, THC, and NOx) were employed. Ambient air monitoring stations were also deployed both upwind and downwind of the unit to monitor any air contamination from the operation of the unit beyond the defined site perimeter.

Table 8 shows the typical range of organic and metallic contaminants in the waste feed excavated from the lagoon after the material was blended into a matrix with sand, soil and lime in order to facilitate its handling. The primary organic of concern was the PCB, while the primary metal of concern was lead. Other characteristics such as heating value and moisture are also shown.

Table 8. Waste Feed Solid Matrix Properties
(Unit is micrograms per gram feed, except percent specified)

| | | | | |
|---|---|---|---|---|
| PCB (total) | 3480 | to | 5850 | |
| Heptachlorobiphenyl | 940 | to | 2200 | |
| Hexachlorobiphenyl | 1100 | to | 1700 | |
| Pentachlorobiphenyl | 200 | to | 490 | |
| Tetrachlorobiphenyl | 400 | to | 830 | |
| Trichlorobiphenyl | 570 | to | 820 | |
| Dichlorobiphenyl | 120 | to | 190 | |
| Ethyl benzene | 40 | to | 140 | |
| Methylene chloride | 80 | to | 120 | |
| Toluene | 130 | to | 300 | |
| Xylene | 280 | to | 480 | |
| Lead | 0.44 | to | 0.59 | percent |
| Antimony | 2.1 | to | 3.6 | |
| Arsenic | 2.0 | to | 2.9 | |
| Cadmium | 3.9 | to | 4.6 | |
| Chromium | 20 | to | 24 | |
| Copper | 44 | to | 55 | |
| Strontium | 50 | to | 62 | |

| | |
|---|---|
| Vanadium | 7 to 11 |
| Zinc | 950 to 1100 |
| Moisture | 14.2 to 16.6 percent |
| Carbon | 7.0 to 7.8 percent |
| Sulfur | 1.8 to 2.5 percent |
| Chlorine | less than 0.1 percent |
| Ash | 70 to 75 percent |
| Btu value (HHV) | 1640 to 2065 Btu/lb |

Presented below is a summary of the results related to each of the objectives for the test program (Ref. 12):

a. Destruction and Removal Efficiency (DRE)

Table 9 shows that the unit successfully achieved a DRE in excess of 99.99% for the PCB contaminants, thus satisfying the required RCRA standard. TSCA regulations, which require 99.9999% DRE, were not applicable since the contaminated material at the site contained less than 50 ppm of PCBs. Operational temperatures of approximately 1900 F in the secondary combustion chamber and more than 3 seconds of residence time, instead of the TSCA-mandated 2200 F and 2 seconds level, accounted for the unit's satisfactory operation in this situation. Residual PCBs in the ash were below the 1 ppm target level mandated by Region IV thereby achieving one of the most important test objectives.

Table 9. Stack Emissions Data

| Date of Run | DRE for PCB (percent) | Particulates Grains/DSCF @ 7% O2 | HCl in g/hr | SO2 in g/hr |
|---|---|---|---|---|
| 8/1/87 | 99.99967 | 0.1590 | <0.8 | 27.24 |
| 8/2/87 | 99.9988 | 0.0939 | 8.6 | 1070.0 |
| 8/3/87 | 99.99972 | | | |
| 8/4/87 | 99.99905 | 0.0768 | 2.9 | 22.0 |
| 8/4/87 (Duplicate) | | 0.0761 | 2.7 | 20.6 |

b. Particulate Emissions

As shown in Table 9, the Infrared System at the Peak Oil site demonstrated problems with particulate emissions and failed to meet the regulatory limit of 0.08 grains/dscf at 7% O2 (by volume) on two of the 3 days they were measured. Emission control system modifications and maintenance before the second test run appear to have been responsible for lowering particulate emissions and eventually meeting RCRA standards in the last two runs.

Interpretation of the data indicates that the inability of the unit's emissions control system to meet particulate emissions requirements was probably due to the lead content in the waste feed and the subsequently high lead oxide loading in the feed to

the emissions control equipment.

c. Acid Gas Emissions

The emissions of HCl and SO2 are also shown in Table 9. The HCl emissions were relatively low since the chlorine concentration in the waste feed was below the 0.1 weight % detection limit. An actual HCl removal efficiency could therefore not be determined. The more difficult to remove SO2 constituent was reduced by an average of 99.1 weight %. With sulfur at approximately 2 percent in the waste feed or a sulfur input rate of about 150 pounds per hour, SO2 emissions were under 2.5 pounds per hour at a maximum measured rate of 1070 g/hr.

d. Metals Fixation/Ash Leaching

One of the objectives of this test program was to determine the fate of heavy metal contaminants in the waste feed and whether any metals remaining in the ash were significantly reduced in concentration or would be stabilized in the ash residue and other solid effluents rendering the ash potentially suitable for delisting as a hazardous waste. The solid waste feed, furnace ash, and scrubber effluent solids were subjected to both the current Toxicity Characteristic Leaching Procedure (TCLP) and the EP Toxicity leaching tests.

The results on the waste feed for both TCLP and EP testing showed that the waste feed exceeded regulatory limits only for lead. The TCLP regulatory limit for lead of 5.0 mg/l was exceeded in one sample of waste feed at 8.8 mg/l, while other samples showed values of 2.5 to 3.5 mg/l. However, the EP regulatory limit (also 5.0 mg/l) was exceeded for lead in the waste feed by larger amounts, namely values of 24.0 to 29.0 mg/l and one sample investigation (though not within acceptable spike recovery limits) showed 57.0 mg/l. All other metals tested for their TCLP and EP values in the waste feed (eight metals total) were found to be below regulatory levels.

For the ash residue, the results of TCLP and EP testing are summarized in Table 10. Here, TCLP results were lower than regulatory limits in every case. However, the EP results again showed a regulatory limit exceedence for lead which would probably prevent delisting of the ash residue even though the other metals appeared well below their regulatory limits.

Similarly, for the scrubber water effluent solids, Table 10 shows that again the EP testing values for lead would prevent the material's delisting, while other metals were found to pass the regulatory levels.

Thus, the hoped-for result that lead and other heavy metals would somehow be inactivated by some process of conversion into non-leachable forms was not met (if EP test results are used and not the TCLP ones).

Table 10. Leaching Test Results

| Metal | Regulatory Level mg/l | Ash EP Toxicity avg. mg/l | Ash TCLP Test avg. mg/l | Scrubber Effluent Solids EP Test avg. mg/l | Scrubber Effluent Solids TCLP Test avg. mg/l |
|---|---|---|---|---|---|
| Arsenic | 5.0 | 0.020 | 0.007 | ND | <.22 |
| Barium | 100 | 1.35 | 0.25 | <.56 | <.80 |
| Cadmium | 1.0 | 0.98 | 0.008 | 0.5 - 1.9 | <.22 |
| Chromium | 5.0 | 0.57 | 0.037 | <.65 | <.08 |
| Lead | 5.0 | 31 | 0.011 | 3.1 - 40.0 | .12-.38 |
| Mercury | 0.2 | 0.0015 | ND | ND | ND |
| Selenium | 1.0 | ND | 0.031 | ND | ND |
| Silver | 5.0 | 0.031 | 0.059 | <.04 | <.06 |

ND = not detectable

e. Organics in Ash or Scrubber Effluent Solids

TCLP testing for organic materials other than PCB was done on the waste feed, the ash residue, and the scrubber solid Samples. The results, which involved testing for some 36 organic hazardous compounds, will be reported in EPA's upcoming final report. However, other than those compounds reported in Table 8 for the waste feed material, all 36 compounds were generally found to be either non-detectable or far below any TCLP regulatory levels.

f. Metals Emissions from the Stack

The largest mass release of metals measured in the stack emissions was that of lead. The specific amounts varied from a release of 2000 grams per hour of lead for the first test run (on 8/1/87) down to a range of 780-1000 grams per hour in subsequent runs where changes were made to the operation of the pollution control system. It is interesting to note that the calculated net input feed rate of lead from the waste ranged between 17,000 to 19,000 grams per hour for the test runs made. Thus, the amount of lead exiting the stack represented only about 11.2% of the feed rate of lead for the first run and between 4.2 to 5.5% for subsequent runs. Also, it should be noted that lead (or lead compounds) represented 54 to 60% of the mass of particles from the stack.

In total, 30 different metals were sampled for and analyzed in the stack particulate material. Other than lead, the next highest amounts of metals emitted as particulate were measured to be zinc (16-17 grams per hour), sodium (31-34 grams per hour), and chromium (0.51 - 0.53 grams per hour). Stack sampling and analysis for chromium VI concentrations yielded results of less than 160 micrograms per cubic meter.

A partial listing of the data for metals is presented in Table 11. Presented there are 11 metals in terms of

their levels in the waste feed, in the ash residue, and their levels emitted via the stack gas particulate material.

Table 11. Metals Analysis

| Parameter | Solid Waste Feed micrograms per gram | Ash micrograms per gram | Average Stack Emission Rate grams/hr |
|---|---|---|---|
| Antimony | 2.15 | 3.3 | .13 |
| Arsenic | 2.55 | 2.6 | .065 |
| Cadmium | 4.15 | 4.1 | 3.4 |
| Chromium | 22 | 27 | .54 |
| Copper | 49 | 64 | .37 |
| Lead | 4800 | 6400 | 1150 |
| Mercury | ND | ND | ND |
| Sodium | 5550 | 5600 | 33 |
| Strontium | 57 | 76 | .017 |
| Vanadium | 9 | 13 | <.036 |
| Zinc | 1030 | 1060 | 16 |

ND = not determined

g. Dioxins and Furans

Since PCB was in the waste, it was desirable to investigate whether there may have been any significant levels of dioxins and/or furans in the lagoon and thus in the waste matrix processed by the Infrared System. Sampling and analysis for these compounds was conducted for the waste matrix, the ash, the scrubber waters, scrubber solids, and the stack gas.

All of the above analyses resulted in less-than-detectable levels of these compounds as summarized below for TCDD, TCDF, PCDD, and PCDF (tetra- and poly-chlorinated dibenzo dioxins and furans):

| Sample | TCDD | PCDD | TCDF | PCDF | Detection Limit |
|---|---|---|---|---|---|
| Waste feed matrix | ND* | ND | ND | ND | 1.1 ppb |
| Ash after treatment | ND | ND | ND | ND | 1.4 ppb |
| Scrubber water | ND | ND | ND | ND | 0.022 nanograms per liter |
| Stack gas | ND | ND | 0.47** | ND | 0.34 micrograms cubic meter |

*ND = Non-detectable
**Reported for one out of 4 tests

3. Current Technology Status

The Infrared System is, so far, probably the most used technology of all the innovative thermal technologies for both RCRA-waste destruction and Superfund waste remediation.

4. Technology Advantages and Disadvantages

The technology has the ability to more accurately control residence time and temperature in the primary combustion chamber (PCC) compared to other technologies. However, the waste feed should be pretreated so as not to exceed recommended size limitations. If the waste is a liquid, it should be mixed with sand, or other solid material, in order to destroy it effectively in the PCC.

E. Plasma Arc

1. Process Description (Ref. 2)

The plasma arc technology has been used in the United States space program. The evaluation of heat shields that protect space vehicles on re-entry required an intense heat source with plasma characteristics.

Plasmas have been referred to as the fourth state of matter since they do not always behave as a solid, liquid or gas. A plasma may be defined as a conductive gas flow consisting of charged and neutral particles, having an overall charge of approximately zero, and all exhibiting collective behavior. The plasma, when applied to waste disposal, can best be understood by thinking of it as an energy conversion and energy transfer device. The electrical energy input is transformed into a plasma with a temperature equivalent of up to 18,000 F at the centerline of the reactor. As the activated components of the plasma decay, their energy is transferred to waste materials exposed to the plasma. The wastes are then broken into atoms, ionized, pyrolyzed and finally destroyed as they interact with the decaying plasma species. The heart of this technology is that the breakdown of the wastes into atoms occurs virtually instantaneously and no large molecular intermediary compounds are produced during the kinetic recombination.

2. Case Study 1: Mobile Plasma Arc Unit (Ref. 13)

The New York State Department of Environmental Conservation (NYSDEC) Division of Solid and Hazardous Waste and the U.S. Environmental Protection Agency (USEPA) Hazardous Waste Engineering Research Laboratory established a cooperative agreement in 1982 for the construction and testing of a mobile plasma arc system for the high-efficiency destruction of hazardous wastes.

Figure 7 shows a process diagram of the Plasma Pyrolysis System which consists of a liquid waste feed system, plasma torch, reactor, caustic scrubber, on-line analytical equipment and flare. The system is rated at 4 kg/min or approximately 55 gallons per hour of waste feed. Product gas production rates are about 5-6 m3/min prior to flaring. For the purposes of this program, a flare containment chamber and 10-meter stack were constructed to facilitate testing. After flaring, the stack gas flow rate is approximately 30-40 standard m3/min.

A gas chromatograph is installed in the System's mobile trailer to provide information on bulk gas composition. Pre-flare gas

samples are analyzed for hydrogen, carbon monoxide, carbon dioxide, water, nitrogen, methane, ethylene, ethane, acetylene, propane, propylene and 1-butene. A Hewlett-Packard Model 5792A gas chromatograph is also coupled to a Hewlett-Packard Model 5970A mass selective detector and used to analyze pre-flare gas samples for waste feed residuals.

One-hour carbon tetrachloride (CCl4) tests were conducted in Canada to demonstrate the destruction of a simple chlorinated compound and to demonstrate effective HCl removal by the scrubber. The CCl4 was introduced into the system in a blend of MEK (methyl ethyl ketone), ethanol, and water at a rate of 1 kg CCl4 per minute. The stack testing was conducted by GCA Corporation. Results of the three tests are presented in Table 12.

The results indicate that the system is capable of achieving destruction and removal efficiencies much greater than the 99.99% required under RCRA for this listed waste.

Table 12. Carbon Tetrachloride Test Results

| | Run 1 | Run 2 | Run 3 |
|---|---|---|---|
| Date | 2/18/85 | 2/26/85 | 2/26/85 |
| Sample Time, min. | 60 | 60 | 60 |
| Feed Rate, L/min | | | |
| CCl4 | 0.63 | 0.63 | 0.63 |
| MEK mixture | 2 | 1.6 | 2 |
| Total Mass Fed, CCl4, kg | 60.0 | 60.6 | 60.6 |
| Chlorine Loading, mass % | 35 | 40 | 35 |
| Reactor Operating Temperature (C) | 974 | 1008 | 1025 |
| Plasma Torch Power, kW | 280 | 298 | 300 |
| Average Stack Gas Flow Rate, dscfm | 1,346.3 | 1,048.2 | 1,052.7 |
| dscmm | 38.13 | 29.69 | 29.81 |
| Average temperature (C) | 893.3 | 807.1 | 667.3 |
| NOx conc., ppm (v/v) | 106 | 92 | 81 |
| Emission Rate, kg/hr | 0.46 | 0.31 | 0.28 |
| CO conc., ppm (v/v) | 48 | 57 | 81 |
| Emission Rate, kg/hr | 0.13 | 0.12 | 0.17 |
| O2 percent | 12.7 | 14.4 | 15.1 |
| CO2, percent | 6.0 | 5.7 | 4.9 |
| HCl, mg/dscm | (1) | 137.7 | 247.2 |
| Emission Rate, kg/hr | (1) | 0.25 | 0.44 |
| CCl4 conc., ppb | <2 (2) | <2 (2) | <2 (2) |
| Emission Rate, mg/hr | <29.3 | <22.8 | <22.9 |
| Scrubber Effluent Flowrate, L/min | 30.0 | 30.0 | 30.0 |
| CCl4 conc., ppb | 1.3 | 5.5 | 3.3 |
| Discharge Rate, mg/hr | 2.3 | 9.9 | 5.9 |
| Destruction Removal Efficiency (3) | | | |
| CCl4, percent DRE | 99.99995 | 99.99996 | 99.99996 |

(1) Invalid data.
(2) The detection limit of 2 ppb CCl4 in the stack gas was used to calculate the CCl4 mass emission rate for each run.
(3) The DRE is based on stack emissions and excludes scrubber effluent.

Three 1-hour tests using PCBs were also conducted to determine the DRE for PCBs and to acquire operating data for this environmental contaminant. Upon reaching a product gas temperature of 2000 F at the reactor exit while using MEK/MeOH (methanol) as the feed material, the feed was then switched to a blend of PCBs, MEK, and MeOH. The scrubber water was retained before discharge to sewer to ensure that the concentration of BaP, PCBs, dioxins and furans did not exceed criteria established by Canadian regulatory authorities. Operating data are presented in Table 13.

Table 13. Operating Data for PCB Run #1

| | |
|---|---|
| Elapsed operating time: | 70 min. at operating temperature |
| Feed rate<br>Total feed- | 3.09 L/min (liters/min)<br>2.83 kg/min |
| PCB feed - | 0.40 kg/min |
| Feed Composition (mass) | 14.1% PCB<br>11.0% TCB*<br>74.9% MEK/MeOH |
| Reactor Operating Temperature | 1136 C |
| Plasma Torch Power | 327 kW |

*Trichlorobenzene

The stack gases were monitored for particulates, PCBs, dioxins, furans, NOx, HCl, flow rate, and temperature. For these runs the stack monitoring was conducted by IMET, Inc. (Markham, Ontario). The sampling and analysis program included the necessary quality assurance/quality control protocols. The procedures and equipment were standard. A summary of the results is presented in Table 14.

Table 14. PCB 1-Hour Test Results

| | Run 1 | Run 2 | Run 3 |
|---|---|---|---|
| Date | 12/5/85 | 12/17/85 | 1/16/86 |
| Sample Time, min. | 50 | 60 | 60 |
| Stack Gas Parameters | | | |
| Flow rate, dscmm | 37.9 | 45.0 | 38.1 |
| Temperature (C) | 836 | 678 | 962 |
| NOx, ppm | 117 | N/A | 139 |
| HCl, mg/dscm | N/A | 43 | 68 |
| O2, percent | 14 | 14.5 | 16.5 |
| CO2, percent | 5.5 | 5.0 | 3.0 |
| CO, percent | 0.01 | 0.01 | 0.01 |
| Total PCB, (1) | <0.013 | 0.46 | 3.0 |
| ug/dscm (2) | <0.013 | 0.32 | <0.011 |
| Total Dioxins, ug/dscm | 0.076 (3) | <0.43 | <0.13 |
| Total Furans, ug/dscm | 0.26 | 1.66 | <0.30 |

| | | | |
|---|---|---|---|
| Total BaP, ug/dscm | 0.18 | 0.45 | 2.8 |
| Scrubber Effluent Parameters | | | |
| Effluent Flowrate, L/min | 41 | 36 | 33 |
| Total PCB, ppb (1) | 1.56 | 2.15 | 9.4 |
| (2) | 0.06 | 4.7 | <0.01 |
| Total Dioxins, ppt | 5.8 | <259 | <1.05 |
| Total Furans, ppt | 1.5 | 399 | <1.05 |
| Total BaP, mg/L | 0.04 | 0.92 | 2.0 |
| Destruction Removal Efficiency | | | |
| PCB, percent DRE | | | |
| (1) | 99.99999 | 99.99994 | 99.9999 |
| (2) | 99.999999 | 99.99997 | 99.999999 |

(1) These values are based upon monodecachlorobiphenyl.
(2) These values are based upon tridecachlorobiphenyl.
(3) No tetra or penta dioxins were detected at 0.05 ng on a GC column, except for Run #1 where 0.06 ng tetra dioxin was reported.

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3. Case Study 2: Plasma Arc for Unopened Capacitor Destruction (Ref. 14)

A schematic of this system is shown in Figure 8. (Ref. 14). The research on this system is sponsored by the Electric Power Research Institute (EPRI) and Arc Technologies Company (ATC) which is a joint venture of Chemical Waste Management Inc. and Electro-Pyrolysis, Inc. The purpose is to destroy whole, unopened PCB capacitors at the rate of 3000-5000 pounds per hour. The sponsors have obtained RCRA permits for the construction of the system in Model City, New York and are in the process of constructing the unit.

Basically, the process involves four (4) steps as follows (as coded on Figure 8):

Step 1: A whole, unopened PCB capacitor is fed into a molten metal (iron) bath.

Step 2: The capacitor shells melt and the internal organic components (PCBs) are subjected to intense radiation from the plasma arc and heat from the molten metal. As a result, the PCB fluids evaporate and decompose.

Step 3: The PCB and/or decomposition products are further directed through the plasma arc in the vicinity of the high current (DC) arc for complete destruction.

Step 4: The products are channeled to a scrubber system where any inorganic materials in capacitors are converted to inert solid residues. Metals may be recovered if desired from both the metal bath and scrubber ash.

4. Current Technology Status

Since the Canadian tests, Westinghouse has built a mobile plasma unit (Pyroplasma) of 3 gallons/minute (1 ton/hr) capacity. Also, for the same high-temperature application, Westinghouse constructed a "Westinghouse Electric Pyrolyzer" for contaminated soil detoxification.

The Westinghouse Electric Pyrolyzer uses electric energy to heat the waste feed to about 3000 F. At this temperature, the organic contaminants are destroyed by decomposition to carbon monoxide and water, and the inorganics melt to form a glass-like fluid which is removed. Both the Pyro-plasma and the Pyrolyzer units have been selected for EPA's SITE program tests. However, no Superfund site has yet been identified for testing.

5. Technology Advantages (Ref. 2)

a. Since radiative heat transfer proceeds as a function of the fourth power of temperature, a plasma system has very intense radiative power and therefore is capable of transferring its heat much faster than a conventional flame.

b. Organic chlorides are known to dehydrogenate when excited by the ultraviolet radiation which is abundant from thermal plasmas.

c. Because the plasma arc for waste destruction is a pyrolytic process, it virtually does not need oxygen at all. Compared to conventional incinerators which normally require about 150% excess air to ensure proper combustion, the plasma arc will save the energy required to heat the excess air to the combustion temperatures and will thereby produce significantly less oxygenated by-products that would otherwise need to be treated in downstream equipment.

d. The process has a very short on/off cycle.

e. Because of its compactness, a plasma arc system has potential for use in a mobile trailer for movement of the system from site to site.

6. Technology Disadvantages (Ref. 2)

a. Because the temperatures are so high (about 18,000 F at the arc's centerline), the durability of the arc and the refractory materials could be a potential problem.

b. Because the arc is very sensitive to many factors such as sudden drops in voltage, the operation of the system requires highly-trained professionals.

## IV. CONCLUSION

The authors felt that the above 5 technologies are the most worthy of compilation for illustrating the development of innovative thermal destruction/incineration technologies since C. C. Lee's 1983 paper. Evaluation of these technologies indicates that in most cases, they can meet either RCRA or TSCA destruction requirements, depending upon which compound or chemical (waste) is to be destroyed. Because of the needs, especially under the SITE program, it is believed that more advanced thermal technologies will be developed as time goes on.

## V. REFERENCES


1. Oppelt, E.T., Incineration of Hazardous Waste a 'Critical Review', the Journal of the Air Pollution Control Association (JAPCA), 37, 5 1987.

2. Lee, C.C., A Comparison of Innovative Technology for Thermal Destruction of Hazardous Waste, proceedings of the first Annual Hazardous Materials Management Conference, Philadelphia, PA, July 12-14, 1983.

3. Lee, C.C., and G.L. Huffman, An Overview of Pilot-Scale Research in Hazardous Waste Thermal Destruction, proceedings of the First International Conference on New Frontiers for Hazardous Waste Management, Pittsburgh, PA, September 15-18, 1985.

4. Ho, M.D. and M.G. Ding, Field Testing and Computer Modelling of an Oxygen Combustion System at the EPA Mobile Incinerator, presented at the American Flame Research Committee International Symposium on Incineration of Hazardous Waste, Palm Springs, November 2-4, 1987 (not included in the Conference Proceedings).

5. Anderson, J.E., U.S. Patent Nos. 4,378,205 and 4,541,796, Oxygen Aspirator Burner and Process for Firing a Furnace, March 29, 1983, and September 17, 1985.

6. Anderson, J.E., A Low NOx, Low Temperature Oxygen-Fuel Burner. Proceedings of the American Society of Metals, 1986 Symposium on Industrial Combustion Technologies, Chicago, Illinois, April 29, 1986.

7. Linak, W.P., J.D. Kilgroe, J.A. McSorley, J.O.L. Wendt and J.E. Durn, On the Occurrence of Transient Puffs in a Rotary Kiln Incinerator Simulator, Part I, Journal of the Air Pollution Control Association (JAPCA), 37, 8, January, 1987.

8. Linak, W.P., J.D. Kilgroe, J.A. McSorley, J.O.L. Wendt and J.E. Durn, On the Occurrence of Transient Puffs in a Rotary Kiln Incinerator Simulaor, Part II, Journal of the Air Pollution Control Association (JAPCA), 36, 8, August, 1987.

9. Beachler, D.S., J. Weldon, and D.M. Pompelia, Bay County, Florida Waste-to-Energy Facility Air Emission Test Results, presented at the Air Pollution Control Association Specialty Conference on Thermal Treatment of Municipal, Industrial and Hospital Wastes, Pittsburgh, Pennsylvania, November 3-6, 1987.

10. White, M.L., W.S. Rickman and H.R. Diot, Transportable Circulating Bed Hazardous Waste Incinerator for Thermal Treatment of Soils, Sludges and Oils, presented at Camp, Dresser and McKee's Emerging Technologies Forum, Palmer House, Chicago, Illinois, June 5, 1987.

11. Rickman, W.S., N.D. Holder, and D.T. Young, Circulating Bed

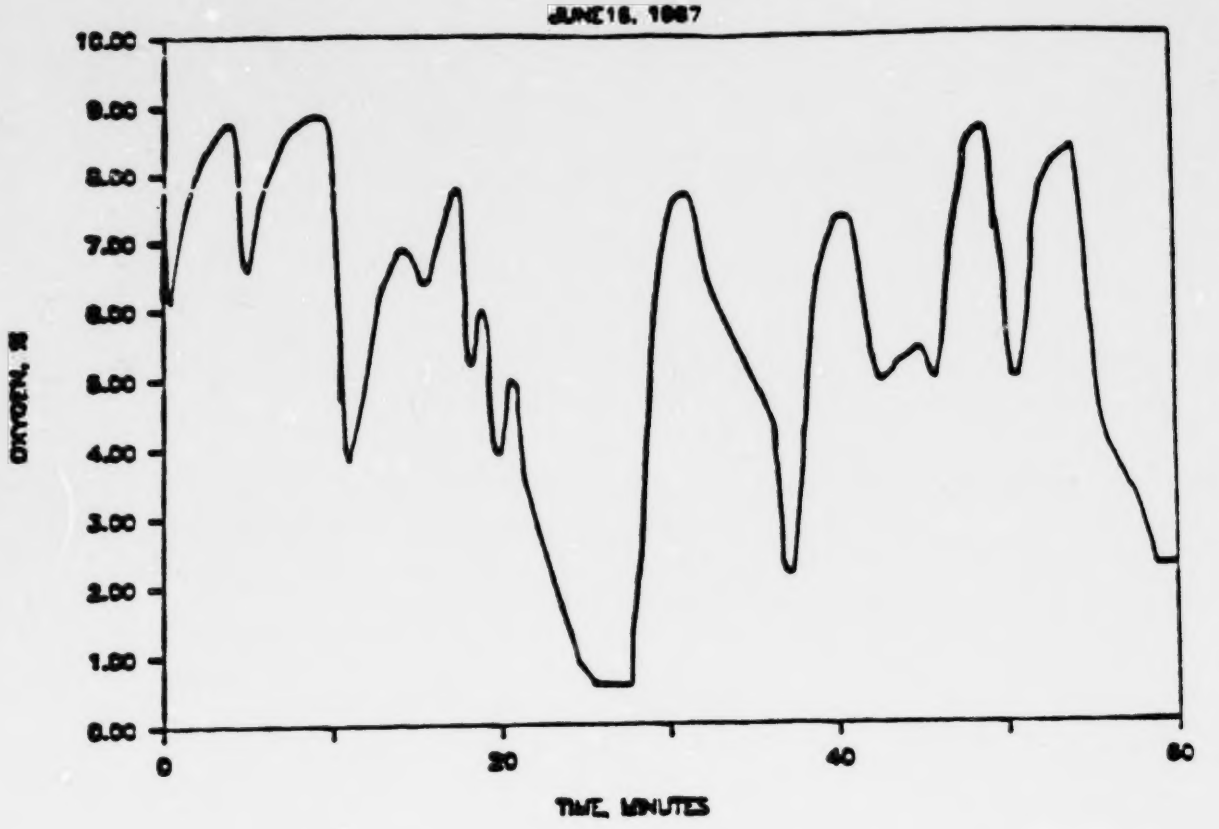
Incineration of Hazardous Waste, AIChE Conference, Philadelphia, Pennsylvania, August, 1984.

12. Oberacker, D.A., H.O. Wall and S. Rosenthal, EPA's Incineration of An Industrial Refinery Lagoon Sludge Using Infrared Furnace Technology, presented at the Second Annual National Symposium on Incineration of Industrial Wastes, San Diego, California, May 9-11, 1988.

13. Kolak, N.P., T.G. Barton, C.C. Lee and E.F. Peto, Trial Burns - Plasma Arc Technology, proceedings of the Twelfth Annual Research Symposium, EPA/600-9-86/022, August, 1986.

14. "Arc Pyrolysis Project", SCA Chemical Services, Inc., Model City, New York, 1986.

Figure 1. Kiln Puffs



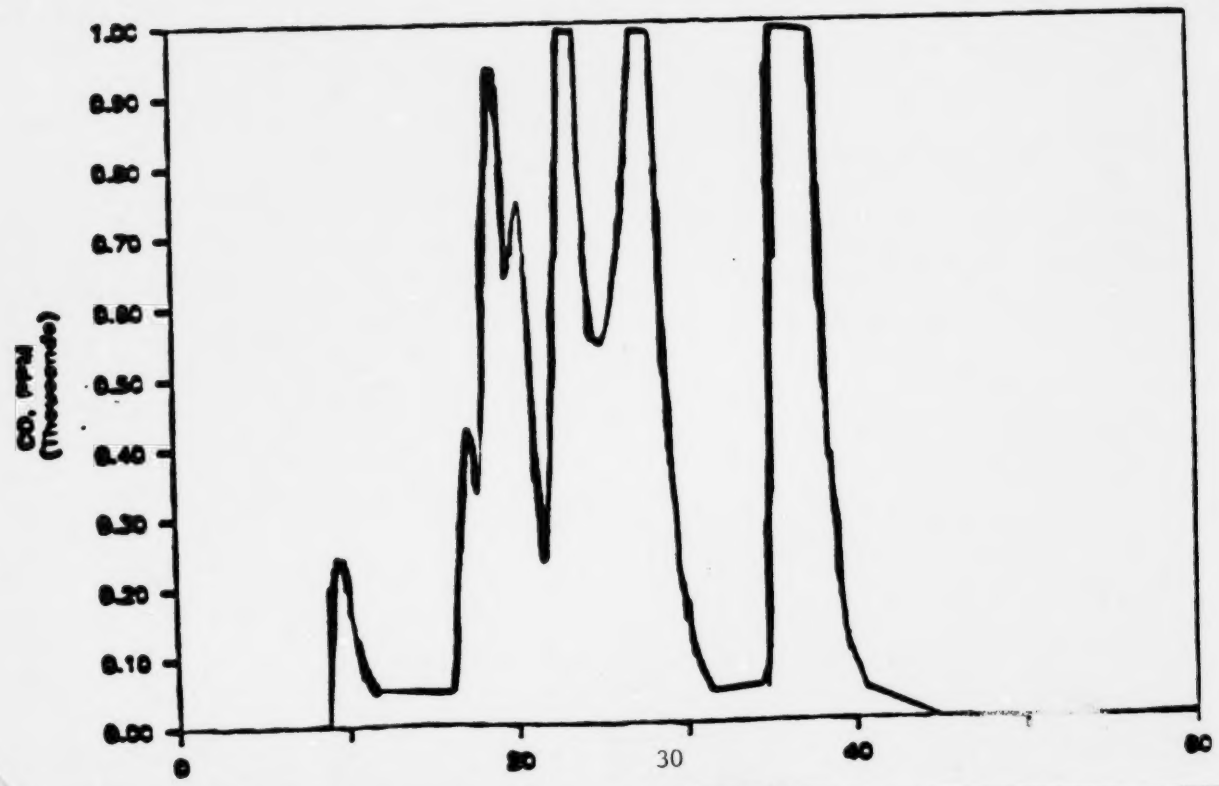
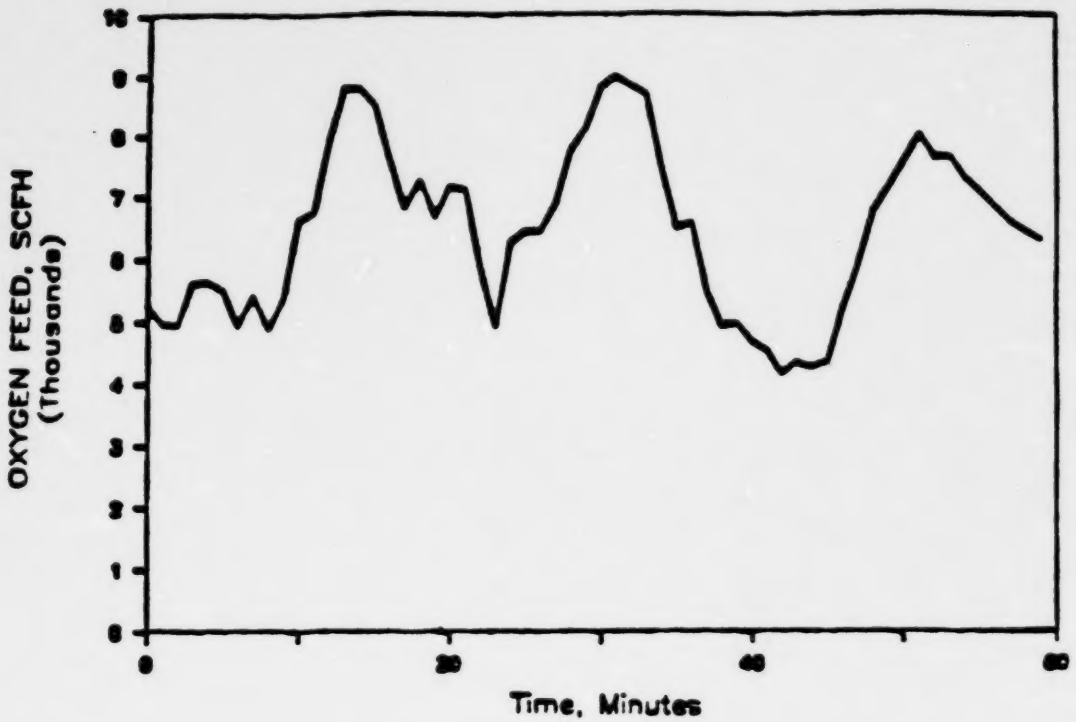
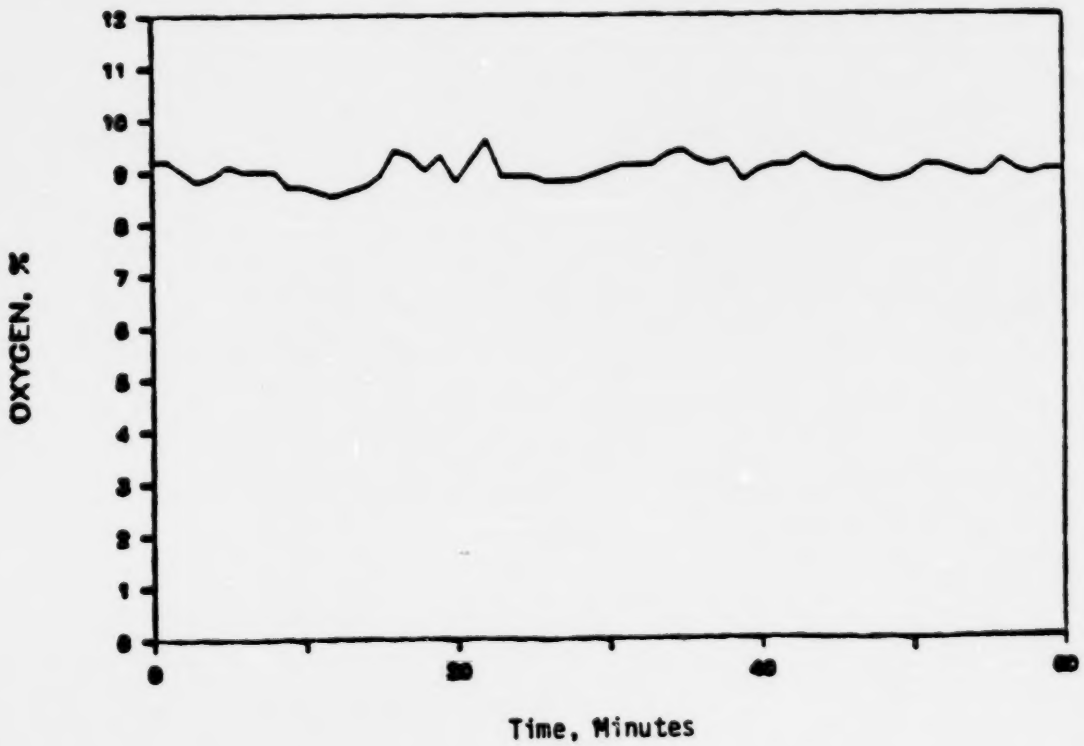



Figure 2. Effects of Oxygen Control



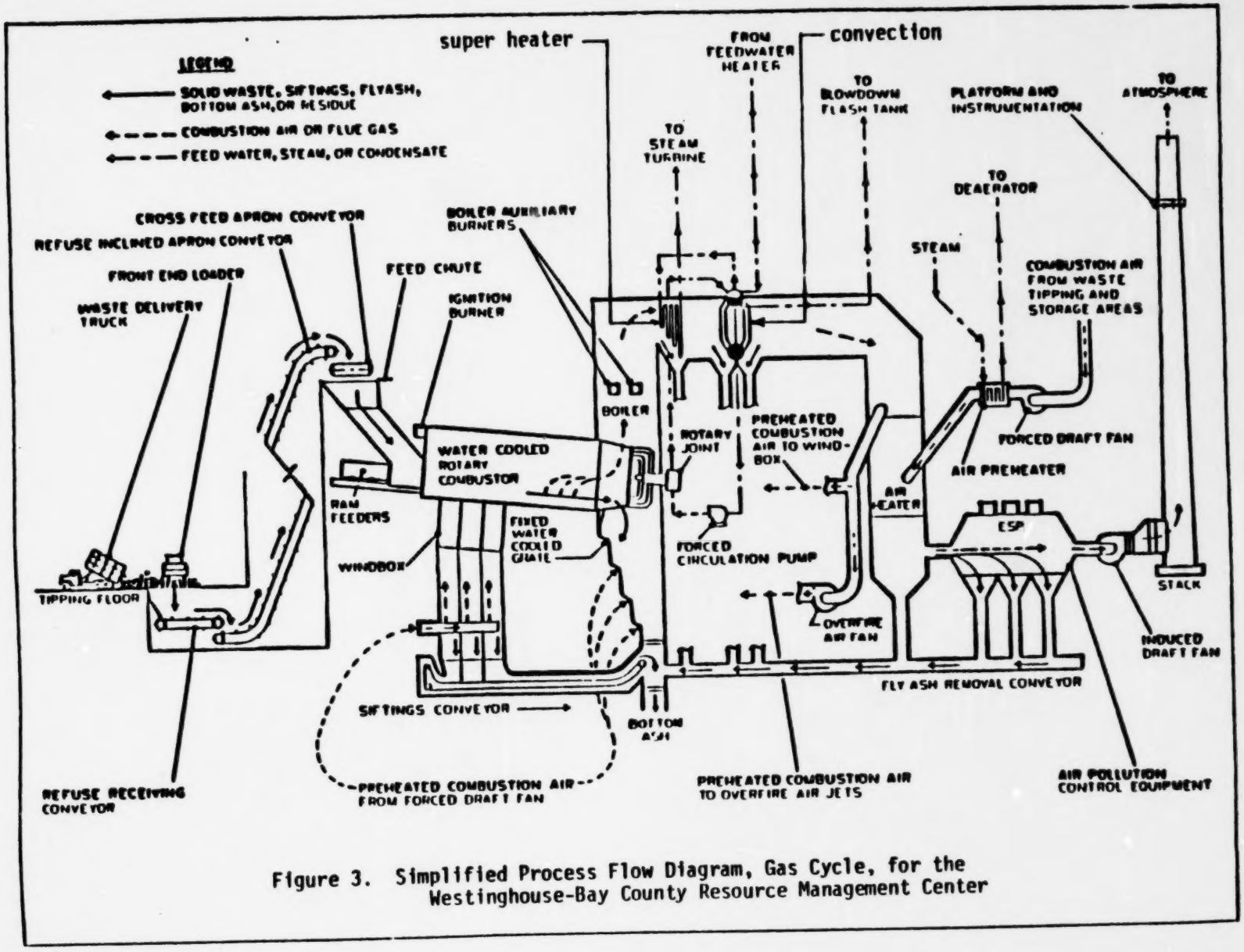



Figure 3. Simplified Process Flow Diagram, Gas Cycle, for the Westinghouse-Bay County Resource Management Center

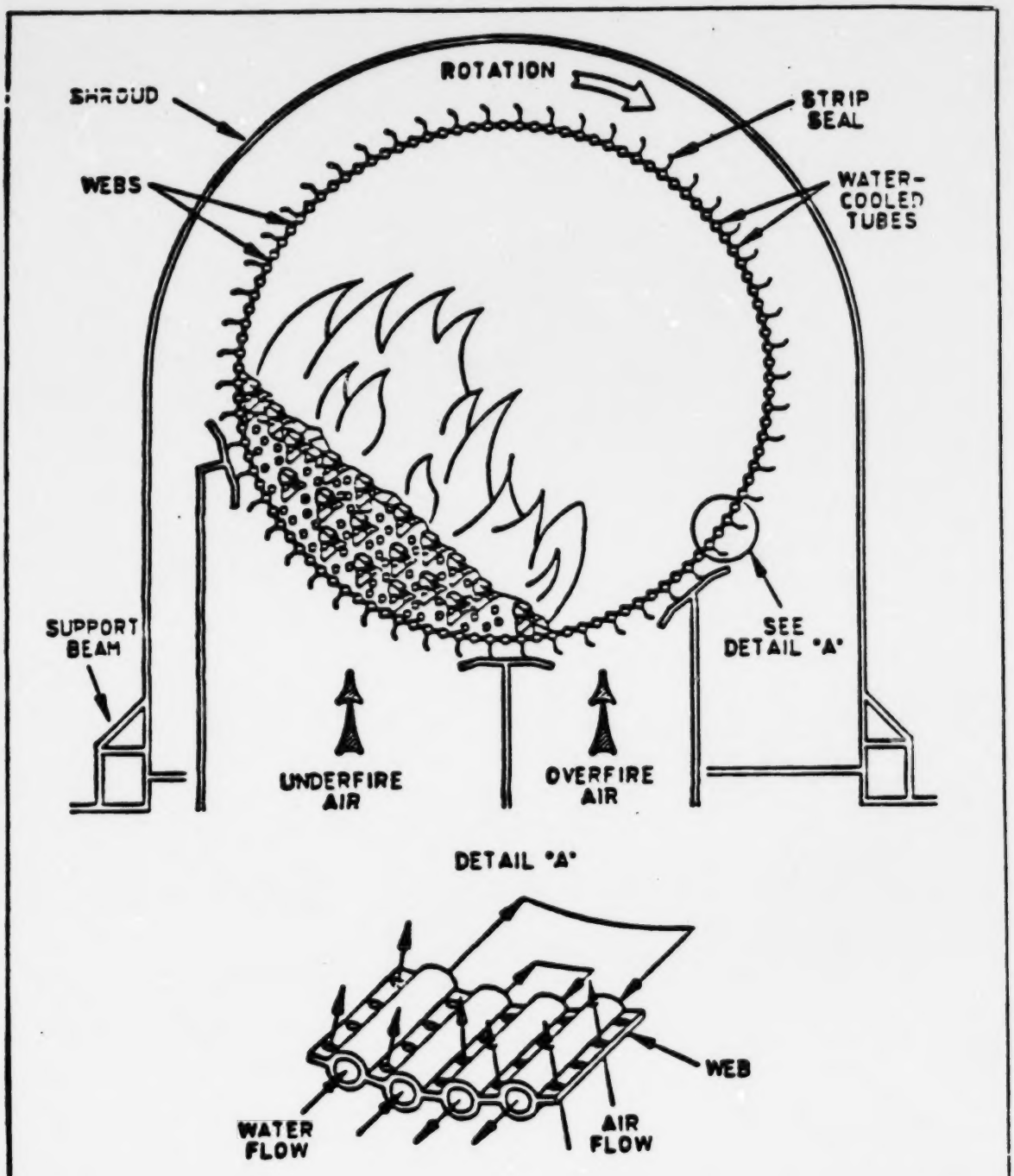



Figure 4. Cross-Section of the Westinghouse/O'Connor Water-Cooled Rotary Combustor

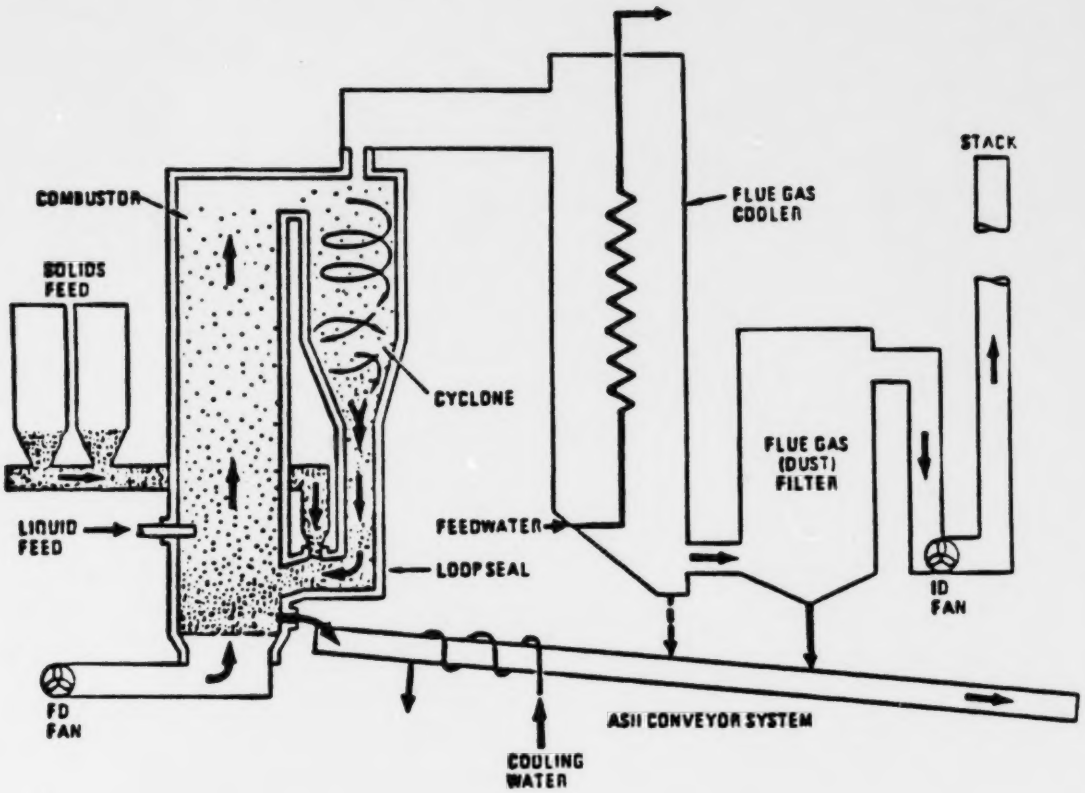



Figure 5. Schematic Flow Diagram of CBC

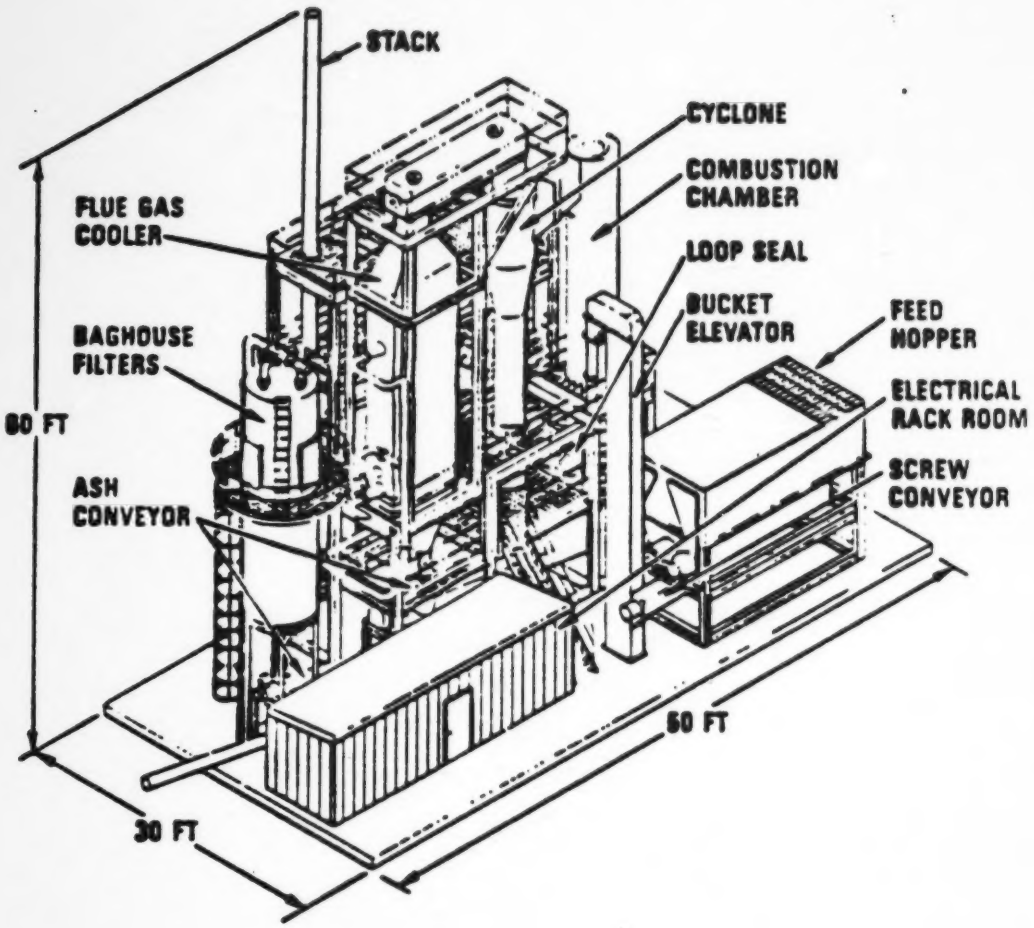



Figure 6. Transportable CBC Plant

A Hewlett-Packard Model 5880A gas

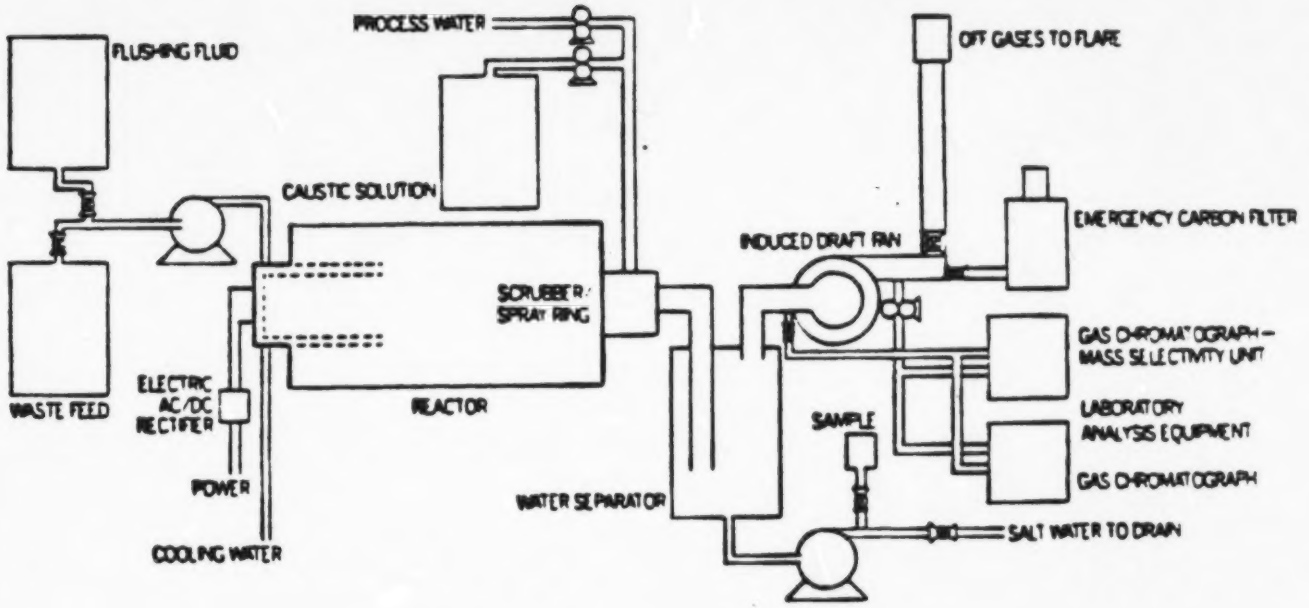



Figure 7. Process Schematic of Plasma Pyrolysis System

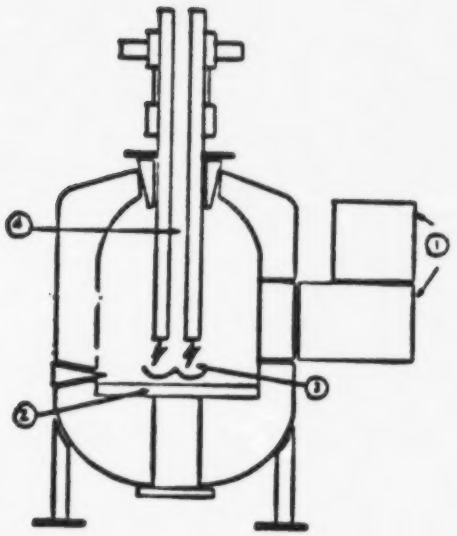



Figure 8. Process Concept of Plasma Arc for Unopened Capacitor Destruction